

EYE PROTECTION

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1. INTRODUCTION AND REQUIREMENT

The U. S. Army has a requirement to provide protection against flashblindness due to nuclear bursts. These requirements are set forth in CDOG paragraphs 1439a(19), and 1439a(20), and in Military Characteristics for Flashblindness Protective Device.

Due to the nature of nuclear warfare, personnel cannot always be aware of the time and location of a nuclear detonation and in much less time than it takes to blind, personnel without protection for the eyes can sustain either temporary damage in the form of flashblindness or permanent injury in the form of chorioretinal burns. As tests at nuclear field exercises have shown, there is a need for concern in the military for protection against flashblindness because these effects can be sustained at distances greatly exceeding the limits for other prompt significant effects. Flashblindness, although of a temporary nature, can render troops combat ineffective for periods of time up to 30 minutes in the most severe cases.

The problem of visual re-adaptation after exposure to a very high intensity light will become a major field problem during nuclear warfare conditions. Basically, the problem is one of re-adaptation to a level sufficient to permit the carrying out of duties necessary for continuance of the mission. In so far as ground troops are concerned this re-adaptation level will mean a fairly high degree of dark adaptation for night operations.

In addition to the requirements previously cited there is also a requirement to provide protection to the individual soldier against the thermal effects of nuclear weapons. Such protection of course must also include the eye and the skin areas surrounding the eyes. In view of the much greater susceptibility to mechanical injury of these areas as compared to other parts of the head, it appears reasonable to assume that less thermal energy will be required to produce mild burns in these areas than in the other regions. Also, burns in these areas probably will have a much greater capability of causing combat ineffectiveness than for example a similar degree of burn on the cheek or neck. The problem of eye protection for Army troops is therefore really threefold: (1) protection against flashblindness, (2) thermal protection, and (3) ballistic fragment protection. The first two are being investigated under the Thermal Protection Program; the third is under the Personnel Armor Program.

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## 2. DISCUSSION

Exposure of the eye to extremely bright sources of light can cause either flashblindness or chorioretinal burns. The flashblindness is temporary while chorioretinal burns usually produce a permanent effect. The recovery time for flashblindness is dependent upon the intensity of the source, the duration of exposure, and the ambient light conditions. The problem, however, is not actually new since personnel such as pilots have been flashblinded by searchlight beams, flashes from rocket firings, and even by lightning flashes. In these cases the auxiliary lighting of the aircraft instrument panels help greatly in combating the mild flashblindness produced.

Three factors contribute to the relative scotoma and lowering of visual acuity during and following exposure to a high intensity light (scotoma is defined as a dark or blind area in the visual field). These are glare from the source, bleaching of the visual pigment with the resultant time interval for re-adaptation, and the formation of after images. Because of the inter-relationship of the above factors the effects of the intense stimuli are complicated and difficult to estimate.

Glare is any degree of light falling upon the retina in excess of that required to see clearly. Glare can be differentiated into three types:

a. Veiling glare: This is created by light uniformly superimposed upon the retinal image which reduces contrast and therefore visibility.

b. Dazzling glare: Adventitious light scattered in the ocular media so as not to form part of the retinal image.

c. Scotomatic or blinding glare: Produced by light of sufficient intensity to reduce the sensitivity of the retina.

All three types of glare are present to a very high degree in nuclear weapon detonations and to varying degrees in other high intensity light sources. The first two, (veiling and dazzling glare) however are only evident while the source is present. The third, blinding glare, is significant because it produces the symptoms, e.g.

(after image formation) which persists long after the source has vanished. An idea of this effect can be obtained by gazing at a bright electric light bulb for a time, then turning the light off. The image of the bulb will remain. This indicates that the retinal image forming processes have persistence. The duration of the scotoma is proportional to the intensity and duration of exposure. If the original stimulation is of sufficient duration and intensity, the sensation will persist with an intensity adequate to greatly reduce or entirely obliterate perception until the effect is dissipated. This is the primary factor in flash blindness. The individual is much more prone to these effects in areas or times of very low ambient light, i.e., darkness. Under these conditions, the pupil is dilated and admits upwards of 50 times more light to the retina than during daylight hours. This fact probably accounts for the lack of retinal burns at Hiroshima where the bomb was detonated against a very bright sky background on a clear day and the pupils were well contracted.

Retinal burns can be obtained from exposure to much less than 1 cal/cm<sup>2</sup> incident at the cornea. At great distances, the size of the burn produced on the retina is directly related to the size of the fireball and distance from the fireball. This is to be expected since the eye acts as a focusing device. The focusing action of the eye also accounts for the fact that very low energies can cause a chorioretinal burn. Low energies are concentrated in a small area raising the energy per unit to levels sufficient to cause damage.

Most of the chorioretinal burns that have been studied were located in the peripheral areas of the retina and may not be an exceptionally grave military hazard even though the damage was permanent. As a note of interest, it might be mentioned that there is very little or no pain associated with such burns.

Vision at night is dependent upon peripheral retinal sensitivity which increases 50,000 to 100,000 times over daylight sensitivity on dark adaptation. Thus, the time for adequate recovery can be quite long and may seriously affect the outcome of a night mission if the personnel are flashblinded.

At one of the weapon tests, two weapons were used and the pulses segmented to determine the effective portions of the burst in causing retinal burns. It was found that

the blink reflex offers no protection. The blink reflex is about 100 to 150 milliseconds duration. The burns and flashblindness were produced in the very early portions of the detonations. In general, it was found that high altitude bursts can cause retinal burns and flashblindness at great distances, and that at low altitudes and ground bursts these effects can also occur far beyond the zones for prompt effects but not quite as far as the very high altitudes. This is especially true of very low yield weapons. For troops using or in the vicinity of use of weapons, eye protection becomes a necessity.

Means of Achieving Eye Protection. - What are the approaches that can be used or that offer promise of a solution to the problem? These can be broken down into two broad categories: (1) those that will yield limited protection, and (2) those that will yield full protection. Full protection can further be broken down into:

- a. The reversible or "multi-shot" item, and
- b. the non-reversible or "one-shot" items.

Limited Protection. - By limited protection we mean the decreasing of the light intensity entering the eye to a level which will only cause a mild case of flashblindness. This can be achieved by use of filters, light or vision restricting goggles or systems which do not quite provide the optical density for full protection.

Filters capable of giving limited protection are either neutral density types or frequency band types. Both of these restrict or cause sufficiently significant changes in visual capacity and acuity to make them unacceptable except possible for very bright daylight use. Under the conditions of very bright background the re-adaption level is close to the exposure level and there is therefore no significant hazard. Their use would be prohibited for night-time conditions or operations.

As mentioned, an approach to some form of immediate limited protection is to limit the amount of light entering the eye by somewhat restricting the vision. A feasibility study along these lines has been made and a rough model of a goggle prepared. This system involves the placement of opaque louvers into the proposed ballistic eye armor. This item should also provide some

degree of thermal protection to the skin areas around the eyes. While vision with these goggles is somewhat restricted in the vertical aspect the forward vision is unhindered. By slightly tilting the head vertical vision can be obtained. Lateral vision will be unhindered except for the portion obstructed by the goggle frame or body.

Full Protection: Mechanical and Electrical Types. - In the full protection areas we can have purely mechanical, electro-mechanical, electro-optical, and photochemical types. Purely mechanical types encompass various sorts of mechanisms. These are usually triggered manually. They are, for eye protection purposes, too slow because of the delay caused by human reaction time. By coupling the mechanical features with automatic electronic systems, the speed of closure can be made to come within the limits desired. The triggering mechanism can be of either spring or other forms of tension loading, gas driven, or use explosive devices.

Electro-optical systems can have either moving parts or no moving parts. Prime examples of these would be polarizing lenses which have to be rotated to become dark or the polarizing effects such as occur in the Kerr or Faraday cells. The rotating lens system would be somewhat the same as the mechanical type, i.e., a sensing element would actuate a motor, spring, or some sort of mechanical device to cause rapid rotation of the polarizing material. The system has somewhat the same drawbacks as the purely mechanical type.

The Kerr Cell type is very different in its operation. Basically, the Kerr Cell is a closed container with ends made of polarizing plates. The cell is filled with a very high purity nitrobenzene. Also incorporated in the cell are electrodes. The nitrobenzene is a birefringent material and if the polarizing plates are set so that they are in the closed position, the unit will not transmit light. If they are set in the open position, light is transmitted. When a sufficiently high voltage (well over 1000 V.) is passed through the nitrobenzene, the nitrobenzene molecules orient themselves in such a manner so as to act as a polarizer and thus negate the effects of the polarizing plates. Under the stressed conditions, if the polarizing plates were initially in the open position, the orientation of the nitrobenzene will then block the transmission of light. The system can be actuated in extremely short time periods. The principal drawback of such a system lies in the fact that heavy accessory

equipment is required. The power amplifiers, power supplies, etc. would weight well over 100 lbs. In addition, the high voltages necessary may be a hazard. Obviously these are not compatible with the concept of the modern soldier where weight and mobility considerations are extremely important.

The Faraday Cell operates on the principle that light will be polarized when passed through a strong magnetic field. Thus, if light from a polarizing material is passed through a strong magnetic field, it will be rotated. If the analyzer portion of the polarizing system was initially crossed, the rotation in the magnetic field will then have the effect of rotating the analyzer to pass the light. If the analyzer was set to pass the polarized light, the rotation will then cause the light to be blacked out.

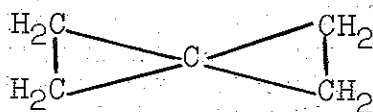
Another system being evaluated utilizes crystal orientation. This type of shutter consists of 2 glass plates with electrical conductive coatings on their inner faces. Between the two glass plates is a suspension of certain crystals in a plasticizer. When these crystals are in random orientation, no light passes. When a current flows between the two conducting surfaces, the crystals orient themselves at right angles to the current flow and allow the light to pass. In such a system a constant current must be maintained to effect light transmission. This principle is very similar to the stressed plate shutter being developed by Ordnance Corps.

Photo-chemical Systems. - Photo-chemical systems are under intensive investigation by a number of firms and military agencies including the Quartermaster Corps. In general, the following mechanisms operate to cause photo-tropic response of organic and inorganic compounds:

- a. Cis-trans re-arrangements.
- b. Ring opening and closure.
- c. Salt isomerism.
- d. Redox reactions.
- e. Color center reactions.
- f. Intra-molecular re-arrangement.
- g. Others.

Cis-trans re-arrangements. - This type of reaction is a form of isomerism. It does not appear to offer too great a promise for our purposes. An example of this type would be the conversion of Stilbene from the cis (non-planar) form to the trans (planar) form. Here the absorption of the cis form has a maximum of 13% at 2800 to 2400 Å while the trans form absorbs about 25% between 3000 and 2400 Å. Most changes of this nature have not yielded a great enough change in absorption characteristics to warrant further investigation.

Ring Opening and Closure. - Ring opening and closure is being studied extensively by the National Cash Register Co. Their interest in this class of compounds arose from their possible use in a memory storage system. They are working on these compounds for the Air Force for use in eye protective devices. The compounds National Cash Register Co. is specifically studying belong to a class of compounds called spirans. These are compounds in which a single atom is a common member of two rings with 3 or more members. An example of a member of this class would be spiropentane:



Salt Isomerism. - Salt isomerism can be exemplified by the triphenylmethane or polymethine types of dyes. The cyanides, borates, sulfides, and hydroxides for example are phototropic when exposed to near ultraviolet light. They change rapidly from the bleached colorless form to deeply colored blues and violets. By side chain substitutions and the use of a polymethine nucleus the color form can be shifted to practically any wavelength. In addition, by adding amines or perchlorates the back reaction can be adjusted to give slow or fast rates.

Work to date indicates that this type of phototrope can change in at least 14 microseconds. The activation wavelengths range from 320 to 400 mμ. They have good molar absorption co-efficients and are adaptable to incorporation in clear films. An additional fact is that they appear to be capable of thermotropism. The principal drawback with these compounds appears to be a lack of resistance to continuous exposure to ultraviolet light. However, this varies with the compound tested. Some compounds will withstand over 100 hours exposure to ultraviolet light.

Redox Systems. - Redox systems are the most common. They occur in both organic and inorganic compounds. The reaction is a transfer of electrons with a subsequent change in the ability to resonate. Compounds of the multivalence metals, iron, chromium, mercury, titanium, etc. in the presence of an electron donor or acceptor can be pressured by light to change valence and therefore color. For example, molybdenum oxide changes from yellow in dark to blue in the light. Titanium oxide in the presence of  $\text{Fe}^{+++}$  can change from white to black in near ultraviolet light. Workers have concluded from a study of  $\text{TiO}_2$  that when light strikes an impurity ion, e.g.,  $\text{Fe}^{+++}$  in a  $\text{TiO}_2$  lattice, an electron moves either into an  $\text{O}_2$  vacancy of the defective crystal structure thus producing an  $\text{Fe}^{++++}$  ion or the electron attaches itself to a  $\text{Ti}^{++++}$  ion to give a colored  $\text{Ti}^{+++}$  ion. Thus, the redox system here can also be considered a form of "F" center coloration. Most organic redox systems bleach instead of darkening when exposed to ultraviolet light. They require a second component. These components capable of causing a back reaction are limited in number.

Color Center Reactions. - Color center types can be illustrated by Hackmanite, a variety of sodalite. These are sodium aluminum silicates. If an impurity such as ions of  $\text{NaCl}$  or sulfides exists in the crystal structure color centers are formed. Hackmanite for example changes from a pink to purple on irradiation with ultraviolet light. Preparation of transparent materials of such solids are difficult. However, the potential for breakdown will probably be low.

Intra-Molecular Re-arrangement. - Intra-molecular conversions are illustrated by the anils. These are usually colored to start and the color deepens greatly on exposure or may change. The color changes are very limited. They usually are a deepening of the original color.

Inorganic Materials. - These include halides of metals etc. Most of these are quite insoluble and difficult to make into transparent layers. In addition, the back reactions are rather slow. However, a number of these show thermotropic characteristics and may find use as an adjunct to the phototropic mechanism.

For Quartermaster Corps purposes the results to date of the various studies being made indicate that the triphenyl methanes and polymethines probably offer the best means of achieving a quick solution to the problem. The

other mechanisms for various reasons are either not readily applicable or require much more work than the isomerism type to make them practical.

The various studies on the organic phototropic compounds have shown a strong dependence of the phototropic reaction to the solvent used. This complicates the Quartermaster Corps' work because we are attempting to incorporate the compounds in the eye armor material, a solid material. Most compounds exhibit a very weak, slow, or no color change when incorporated into a resin or solid substrate or when used by themselves.

Many of the mechanisms mentioned previously have a series of initial steps which are quite similar. The end products varying because of the nature of the original materials. As has been demonstrated by a number of investigators, most of the reactions are initiated by the absorption of light and the consequent raising of the energy states of the orbital electrons to activated singlets or triplets. The chemical reactions such as ring opening, molecular resonance etc., proceed from these energy rich states. Thus, many of the changes observed may be closely related to fluorescence and phosphorescence at least in the initial steps.

### 3. QM EFFORT

The Quartermaster program has been primarily directed towards: (1) the preparation of new phototropic materials in the triphenyl methane and polymethine class, (2) evaluation of systems incorporating phototropic materials, and (3) developing an interim item with one-way characteristics.

The salt isomerism-type of phototropic material was chosen because this class of compounds exhibited good properties for most of the requirements. These compounds exhibit their color change through a resonance phenomenon on being activated by ultraviolet light of .2 to .4 microns. It has been found that by altering the central carbon chain length by side chain substitution that the wavelength of response and final color can be changed. A full range of colors is therefore theoretically possible. The synthesis program has shown that when electron donor substituents such as alkyl, amino, hydroxyl, and alkoxy groups were placed in the molecule a shift in absorption peak to the longer wavelengths was obtained. By the same token, a shift to shorter wavelengths could be obtained by the substitution of electron accepting groups.

Although the color of the dye may be changed and/or intensified at will by the proper choice of substituents, these substituents also have an effect on the phototropic behavior of the material. The phototropic response of a material is dependent upon the resonance states in which the cation exists and to the extent that it acts as a nucleophilic agent. Here again, the electron donor or accepting characteristics of the substituents control the total effects.

In phototropic reactions the dye cation after absorbing the photon, goes to an intermediate or excited state. It is from this excited singlet or triplet state that the reaction products are formed. The colored dye form, the breakdown products, or even a polymerized dye form can all come from this state. The exact nature of the mechanism and the effect of various substituents on the dye cation has not been evaluated. The investigation of structure, resonance state, and mechanisms from a quantum mechanics approach requires more extensive instrumental techniques than are available at this time.

Other areas studied were complete systems, bleaches, effects of concentration and intensity, and quality of the

activating energy. It has been found that certain solvent combinations and resins have major effects on the reaction rates and optical densities obtained. It was initially thought that the dielectric constant of a solvent would be an indication of the effect on the phototropic mechanism. However, it was found that there was no direct correlation between these factors.

The speed of response of a complete system was investigated using a flash technique. A high intensity flash (2400 watt seconds) was used as a source. The response was measured by a photocell and a dual trace oscilloscope. Response times of less than 30 microseconds were observed. Quantum yields approaching one (1) have also been measured using a ferrioxalate actinometer. Two major problem areas are: (1) storage stability, and (2) stability to sunlight. The most effective compounds found to date to increase the stability are phenolics with a second oxygen containing group. However, the increase in stability is at the expense of sensitivity.

#### 4. FUTURE WORK AND PROBLEM AREAS

In the future studies will be continued on:

- a. New phototropic compounds.
- b. Basic studies on mechanisms and kinetics of various phototropic and photochromic reactions.
- c. Investigation of new approaches to solving the eye protection problem.
- d. Work is required in certain areas pertaining to weapon phenomenology to define the problem more accurately:
  - (1) Determination of time-energy history of the first pulse.
  - (2) Determination of spectral distribution of the first pulse with respect to time.
  - (3) Determination of time-illuminance characteristics of the first pulse.
  - (4) More accurate determination of the ultraviolet energy transmission through the atmosphere.
- e. Work is also required in a fundamental study of eye physiology as it relates to flashblindness.
  - (1) Determine whether there is a spectral dependency on the production of flashblindness.
  - (2) Determine the minimum amount of light to cause flashblindness of varying duration when adapted to various ambient illumination levels.
- f. Work is also required in human factors engineering to determine the optimum type of instrument faces for quickest reading after being flashblinded.